REPORT R-408 FEBRUARY, 1969

COORDINATED SCIENCE LABORATORY

CONTEXT MODELING IN A COGNITIVE MEMORY

DANIEL JOSEPH LOMBARDI

UNIVERSITY OF ILLINOIS - URBANA, ILLINOIS

This work was supported by the U.S. Office of Education under Contract OE C-1-7-071213-4557; auxiliary support was provided by the Joint Services Electronics Program (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract DAAB 07-67-C-0199.

CONTEXT MODELING IN A COGNITIVE MEMORY

Daniel Joseph Lombardi

Abstract

This report is concerned with the derivation and description of a model used for structuring the "Rules of the Road" as a data base for a general question answering system. Related work and question-answering processes are also discussed.

ACKNOWLEDGEMENTS

I wish to express my gratitude to Professor R. T. Chien and Professor F. P. Preparata for their guidance, invaluable advice and suggestions throughout the period of research for this report. Thanks are extended to Mrs. Sherry Kallembach for her preparation of this manuscript.

TABLE OF CONTENTS

I. INTRODUCTION

The goal of this project, of which this report is a part, is to develop a general question-answering system. Unlike the previous work done in this area, this system will use natural English as an input language and it will not be dependent upon a pre-determined format for the phrasing of questions. Specifically, this paper deals with the problem of organizing a memory for such a system. The universe has been confined to the "Rules of the Road" to facilitate implementation of the data base.

In Chapter 2, previous work will be discussed in relation to the present model. This will include a brief description of the first model tried and the way it was used to answer questions.

In Chapter 3, the present model will be explained in detail and a few diagrams are given to show how the model is applied to the "Rules of the Road" data base.

In Chapter 4, question-answering schemes will be suggested and examples given.

II. PREVIOUS MODELS

1. Generally Related Models

Among the first to recognize the need for "a data representation that could contain general facts about the relations in the logical system as well as specific facts about the objects in the real problem domain" were Green and Raphael.[1] They developed a question-answering system, called QA1, that utilized such a memory organization. It was an improvement over the SIR system by Raphael[2] in that its list structure memory contained relational information to supplement the various kinds of facts.

This relational information was confined to the areas of part-whole relationships, set membership, set inclusion, spatial relationships and general statistics. This was due in part to the modified predicate calculus representation of information that was used. The subsequent evolution of their systems have proceeded in the direction of automatic theorem proving. This type of model, however, does not lend itself to the more general textual type of data base (e.g., the Rules of the Road) where the relational information needed is more diversified and isn't readily mapped into mathematical terms.

2. Specifically Related Models

The first attempt at a question-answering system using the "Rules of the Road" as a data base (i.e., the R2 system) was implemented by Jensen and Stahl.[3] The organization of their "memory" model took the form of the "Rules of the Road" manual verbatim. Initial processing consisted of placing the manual on tape with the various sentences and title heads being numbered consecutively. The objective was to find a general strategy technique that would retrieve statements from the data base that were relevant to a particular question.

The technique they used was called the maximal phrase relational strategy and consisted of a dictionary, a set of statements and a particular strategy. In brief, the maximal phrase index consisted of the patterns that occurred in the data base that were maximal. In other words, if pattern A was included in pattern B, then pattern A was removed from the index. The result of this technique, when applied to a particular question, was the retrieval of context from the data base that contained the same maximum phrase as was found in the question.

Although this process did not require a restructuring of the data base and had the extremely nice property of being data base independent, it had some rather implicit shortcomings. Its effectiveness as a statement retriever was limited by its inability to detect whether or not a statement was relevant to the specific issue in question. The fact that a maximal phrase matching had occurred simply was not a sufficient criteria for relevancy. Other problems, such as how to deal with pluralization also presented themselves.

In short, although the system had limited success as an efficient statement-retriever, it, nevertheless, provided very valuable insight into the nature of the problems that must be resolved and also into the nature of the maximal phrase technique and the extent of its usefulness.

III. A NEW MODEL

1. Derivation

The philosophy behind modeling the prescribed data base in the following fashion is to construct a comprehensive and coherent structure that relates the fundamental topics of "Rules of the Road" in such a manner as to make them readily accessible to an "uninformed" individual. The system, at present, does not contain any logical deductive ability and consequently everything involved in the model is explicitly stated whether it be an object, an action, or a relation.

Conceptually, the data representation is similar to the one suggested by Green and Raphael.[1] However, in order to increase the comprehensive nature of the model, it was necessary to develop a structure that was not solely dependent on the postulates of predicate calculus. In fact, a completely linguistic approach was used which effectively bypassed the rather stringent limitations imposed by the foregoing mathematical treatment. This approach cannot be used without some compromise, but it did lead to a model with a broad capability that is especially applicable to coherent textual material.

Basically, the model contains three types of information. The first type is of a syntactic nature, and is synonomous with the accepted syntactical formulation of the English language. Words and groups of words are classed as static, dynamic and/or as modifiers. These three classes are represented in the model as static, dynamic and/or modification nodes respectively. The properties of the word or phrase that determine which type of node (i.e., class) it will occupy are analogous to standard English syntactical properties (i.e., noun, verb, adjective, etc.) and will be discussed in detail in the following sections.

The second type of information present in the model is of a semantic nature. This information takes the form of channels in the model and is used in conjunction with pointers to show explicitly the physical relationships between the nodes. It was found that including this type of information in the model almost completely eliminates the relevancy problem encountered by Jensen and Stahl.[3]

Finally, the model contains information in the form of contextual data. This data is expressed with the aid of chosen passages from the "Rules of the Road" manual that are referenced according to the nature of their content in relation to specific static, dynamic and modification nodes.

In view of the amount of material to be covered and the practical constraints imposed by implementation, the model structure itself is based on a comprehensive yet fairly simple organizational procedure. The problem of including all the fundamental topics involved was a relatively simple one. However, if <u>each</u> of these topics is thought of in regard to its interaction with all the conceivably related actions, the number and complexity of these interactions soon becomes prohibitive and the result is an extremely redundant and complicated model. This problem was finally resolved by the introduction of the "data cell" concept. Basically, the data cell is an independent structure within the framework of the model. It is designed to take advantage of the redundancy occuring among actions that refer to individual fundamental topics. The idea is to include in a particular data cell only those fundamental topic constituents that are members of the same set. All the members of this set, or subset, then share the same list of actions included in that data cell. The method is exemplified in Figs. 1-4 and is discussed thoroughly in the following two sections.

2. Outline of Model Structure

I. Data Cell

A. Nodes

1. Static Nodes

a. Major

(1) Independent: These nodes contain an object, a person, or a thing.

(i.e., VEHICLE)

(2) Dependent: These nodes refer to a specific independent major static node or to another dependent major static node. They contain words that are types of the object, person, or thing contained in the independent major static node and in many cases are analogous to adjectives.

(i.e., CAR)

b. Minor Dependent: These nodes contain a definition, an explanation, or general data and refer to a specific major node.

(i.e., 63.2a)

2. Dynamic Nodes

a. Major: These nodes contain an action word, and depending on the nature of the major independent static nodes that they refer to, either specify something that can be done to a major static node or something that can be done by a major static node.

(i.e., $\boxed{\text{RACE}}$)

b. Minor: These nodes contain the explanation of the performance of some action, or some other general data concerning an action.

(i.e., $\boxed{\text{63.2b}}$)

B. Relational Data Channels

1. Operates on a static node and maps into a static node (abbr. nSS where n = 1,2,...10;)

2. Operates on a static node and maps into a dynamic node (abbr. nSD where n = 1)

3. Operates on a dynamic node and maps into a static node (abbr. nDS where n = 1,2,...13)

4. Operates on a dynamic node and maps into a dynamic node (abbr. nDD where n = 1,2,...10)

II. Modifiers

A. adjectives and adverbs (i.e., $\boxed{\begin{matrix}\text{safe}\\ \text{1a}\end{matrix}}$, $\boxed{\begin{matrix}\text{right}\\ \text{2a}\end{matrix}}$)

B. conditions (i.e., $\boxed{\begin{matrix}\text{rain}\\ \text{1b}\end{matrix}}$, $\boxed{\begin{matrix}\text{accident}\\ \text{4b}\end{matrix}}$)

C. locations (i.e., $\boxed{\begin{matrix}\text{two-way}\\ \text{street}\\ \text{1c}\end{matrix}}$, $\boxed{\begin{matrix}\text{hill}\\ \text{4c}\end{matrix}}$)

3. Description and Examples

The foregoing outline shows the two basic parts of the model structure, the Data Cell and the Modifiers with their respective constituents. The model itself is made up of a number of these Data Cells and a list of Modifiers. Each Data Cell is completely independent of the others, therefore permitting certain aspects of the data base to be completely modeled without having to model the data base as a whole in order to cross reference. At present, four data cells have been either fully or partially completed. They are shown in Figs. 1-4. Approximately 10-12 will be needed to completely model "Rules of the Road", but the four shown in this report cover a majority of the information needed. Additional data cells should include Major Independent Static Cells such as: (5) driver, person, pedestrian; (6) accident; (7) traffic law; and (8) alcohol. An example of some of the words to be included as dynamic nodes in data cell (5) would be: follow, yield, pass, weave, use, signal, speed, drive, learn, and travel.

As can be seen from the outline, each data cell consists of two types of nodes: static and dynamic. The terms noun and verb have purposely been omitted since they are not general enough to be used per se. Noun phrase and verb phrase are more closely related but still are not quite general enough.

All the Major Static Nodes in one data cell are related by the fact that the contents of each node in the list of Major Dynamic Nodes can refer to _any_ Major Static Independent or Dependent node within that particular cell. This is the property that defines the boundary conditions for admitting a static constituent to a particular cell. Furthermore, it was found that many of these static and dynamic nodes contained words that have one or more synonyms that are used with equal fluency. This was also found to be the case with the list of modifiers. In order to save space and to simplify the diagrams as much as possible, all the nodes containing words with synonyms have been marked with an asterisk (*) and these synonyms are listed in a dictionary found in the Appendix.

The Relational Data Channels (RDC) are used to relate all the nodes in one cell. This relationship, however, is unidirectional and only goes from major to major or major to minor node. This means that a minor node is never referenced directly. It can only be pointed to by a major node, or combination thereof, using a RDC and the addresses of the modifiers (if any). This will be explained in detail later in the report.

The following four sets contain explicitly the individual components of each type of RDC listed in the outline. These RDC's, although applied to the "Rules of the Road" in this case, are of a very general nature and are, to a great degree, data base independent. No claim is made as to whether or not these relationships are all necessary or sufficient, but a great deal of care has been taken to phrase them in such a way as to eliminate redundancy while retaining flexibility. Also, the majority of them are used in one of the four data cells shown in Figs. 1-4.

Set #1. Operates on a Static Node and maps into a Static Node. (abbr. nSS where n = 1,2,...10)

1. specifies one type of an existing class of objects.
2. specifies the definition or the meaning of an object.

3. specifies the parts of an object.

4. specifies a possible location of an object.

5. specifies the cost or fee of an object.

6. specifies the purpose of an object.

7. specifies how the knowledge of a given object is conveyed.

8. specifies the shape of an object.

9. specifies the color of an object.

10. specifies the number of objects required.

Set #2. Operates on a Static Node and maps into a Dynamic Node. (abbr. nSN where n = 1)

1. specifies an action that is implied or associated with an object.

Set #3. Operates on a Dynamic Node and maps into a Static Node. (abbr. nDS where n = 1,2,...13)

1. specifies an object that is implied or associated with an action.

2. specifies a location of an action.

3. specifies who must perform an action.

4. specifies who may perform an action.

5. specifies the purpose of an action

6. specifies static condition(s) that must exist so that the action referred to can take place.

7. specifies a period of time relevant to an action.

8. specifies who is influenced or effected by an action.

9. specifies whether or not an action is legal, (i.e., permitted, prohibited, etc.)

10. specifies the definition of an action.

11. specifies static conditions that make an action necessary.

12. specifies static conditions whose nature (i.e., good, bad, etc.) determines the degree of proficiency of an action (i.e., how fast, how well, etc.).

13. specifies the distance from an object or from another action, that an action must take place.

Set #4. Operates on a Dynamic Node and maps into a Dynamic Node. (abbr. nDD where n = 1,2,...10)

1. specifies action that is implied or associated with an action.
2. specifies active conditions that must be met before a certain type of action can take place.
3. specifies the purpose of an action.
4. specifies how to perform or accomplish an action.
5. specifies the consequences of an action. (i.e., penalty, reward, etc.)
6. specifies the consequences of an action not performed or performed inadequately.
7. specifies active conditions that make an action necessary.
8. specifies action that should or must be taken under given active conditions.
9. specifies action that may be taken under given active conditions.
10. specifies active conditions that cause an action to take place.

Each of the four sets of RDC's above is made up of a number of explicitly stated relationships that performs the desired mapping operation. These are abbreviated by showing which set the operation belongs to and exactly which one it is. For example, 3DS is the notation used for "specifies who must perform an action," since it is the third member of the dynamic to static (i.e., DS) operator set. This particular RDC would point to a minor static node that would supply the required information.

For example, data cell #2 in Fig. 2 deals with the "driver's license" in one of its Major Independent Static Nodes. In the list of many dynamic nodes that could conceivably relate to the "driver's license" is the one that contains the action word "obtain". Now the RDC, specifically 3DS, can be used to point the way to "who should perform this action" of "obtaining a driver's license." This is accomplished by writing down the relationship, 3DS, and by following it with the address of the Major Independent Static Node that it specifically refers to (i.e., 3DS-1, where 1 is the required address).

This RDC then points to a Minor Static Node that contains the required information. In this case the information is "Almost everyone who wishes to operate a motor vehicle on the streets and highways of Illinois." This is also put into notation by merely specifying the page, paragraph and sentence number from the "Rules of the Road" manual. The above information is found at 4.1 (i.e., page 4, paragraph 1). Furthermore, this same RDC can be used to supply information about a more specific type of drivers' license simply by extending the address to include that of one or more Major Dependent Static Nodes as well. For example, the RDC "4DD" is concerned with "specifying how an action is accomplished." Supposing we were interested in this relation in regard to "obtaining a duplicate license"; then we would look for the RDC identified by the notation 4DD-1e (where "e" is the address of the Major Dependent Static Node containing the word duplicate). This would lead us to the information 9.2b, which reads "by making application therefore and paying the required fee." Also, if a specific address is not given for a

Major Dependent Static Node, then the RDC and the resulting information is assumed to be true for all the Major Dependent Static Nodes of the particular Major Independent Static Node addressed. Furthermore, if a specific address is not given for a Major Independent Static Node, then the information resulting from that particular RDC is assumed to be true for all the Major Independent Static Nodes in the given data cell. An example of this can be seen in data cell #3 in Fig. 3. The RDC "3DD" which "specifies the purpose of an action" refers to the dynamic node containing the word "obey" and points to the Minor Static Node containing the information found on page 27, paragraph 1. This information pertains to the purpose of obeying signals, signs, and markings. These are the words contained in the three Major Independent Static Nodes of the data cell. Therefore, the information in 27.1 is referenced simply using the RDC "3DD" and no additional addresses are necessary. Further details and examples of this set inclusive type of addressing and referencing will be given at the end of this chapter and in Chapter IV.

Before explaining the use of the Modifiers in the model, some other useful notational features of the RDC will be pointed out. Occasionally it is necessary to refer to information that is related to a given major node in more than one way. For instance, a type of red sign is a STOP sign, type being denoted by 1SS, however the meaning of a red sign is to STOP, meaning (or definition) being denoted by 2SS. When a case like this arises, both notations are used on the respective RDC. This procedure is more concise than referencing the same information by two different channels.

The other feature that is used occasionally is that of complementing or negating the RDC. For example, the RDC '8DS' "specifies who is influenced or affected by an action." In data cell #2, shown in Fig. #2, 8DS-1 refers to 'who needs a drivers license' while $\overline{\text{8DS}}$-1 refers to who doesn't need a drivers licence (i.e., "people who are not influenced or affected by the need for a drivers license"). Before continuing, it should be noted that the features mentioned above, like the introduction of the synonym dictionary, are intended to simplify the diagrams as much as possible. Whether or not it is feasible and/or practical to include them in the actual implementation is not yet apparent. Nevertheless, the system can be implemented without them by increasing the number of nodes, pointers and RDC's.

The second part of the model is made up of the list of Modifiers. As seen in the outline the first type of Modifiers used are adjectives and adverbs and consist of words like: 'safe', 'right', 'drunk', etc. Examples of the second type, locations, are: 'one-way street', 'sidewalk', 'hill', etc. Finally, the third type, conditions, contains words such as: 'snow', 'rain', 'fog', 'accident', etc. One or more of these three types of modifiers are at the disposal of every data cell and the entire list of dynamic nodes within each data cell. When it is necessary to reference a modifier on a RDC, it is simply necessary to state the address of that particular modifier after the address of the major static node. The modifiers are necessary because some relationships only exist under specific conditions, or at specific locations or only involve specific types of action.

For example, in data cell #4, shown in Fig. #4, information is given about "how to turn left onto a two-way street." The RDC and the corresponding addresses are, 4DD-3a1c, where 3a and 1c are the addresses of the modifiers "left" and "two-way street" respectively as shown in Fig. 5. Note that in this case there is no address given that refers to the Major Independent Static Node "vehicle." This is because of the fact that there is only one Major Independent Static Node in this particular data cell, and when no Major Dependent Static Node must be cited for a relation to hold, there can be no doubt which node the RDC is referring to. It is important to recognize that leaving the word "vehicle" out of the phrase "how to turn (a vehicle) left onto a two-way street" does not create any ambiguity. There is an a posteriori assumption involved that automatically foregoes the necessity of placing the word "vehicle" in the phrase. It is for this reason that the data cell only has one Major Independent Static Node in the first place. It is only when a relation applies only to a specific type of vehicle (i.e., a Major Dependent Static Node) that it becomes necessary to include the address of this static node with that of the RDC and the modifiers. This address function can be extended to a data cell containing more than one Major Independent Static Node and can be stated in the following way: Whenever a particular RDC, with or without the addresses of any circumscribing modifiers, holds for all the Major Independent Static Nodes in a data cell, it is not necessary to give the addresses of these nodes.

The next chapter gives further examples of this function and shows why it is important, along with how RDC's and addresses can be arrived at given a question.

IV. QUESTION ANSWERING IN THE MODEL

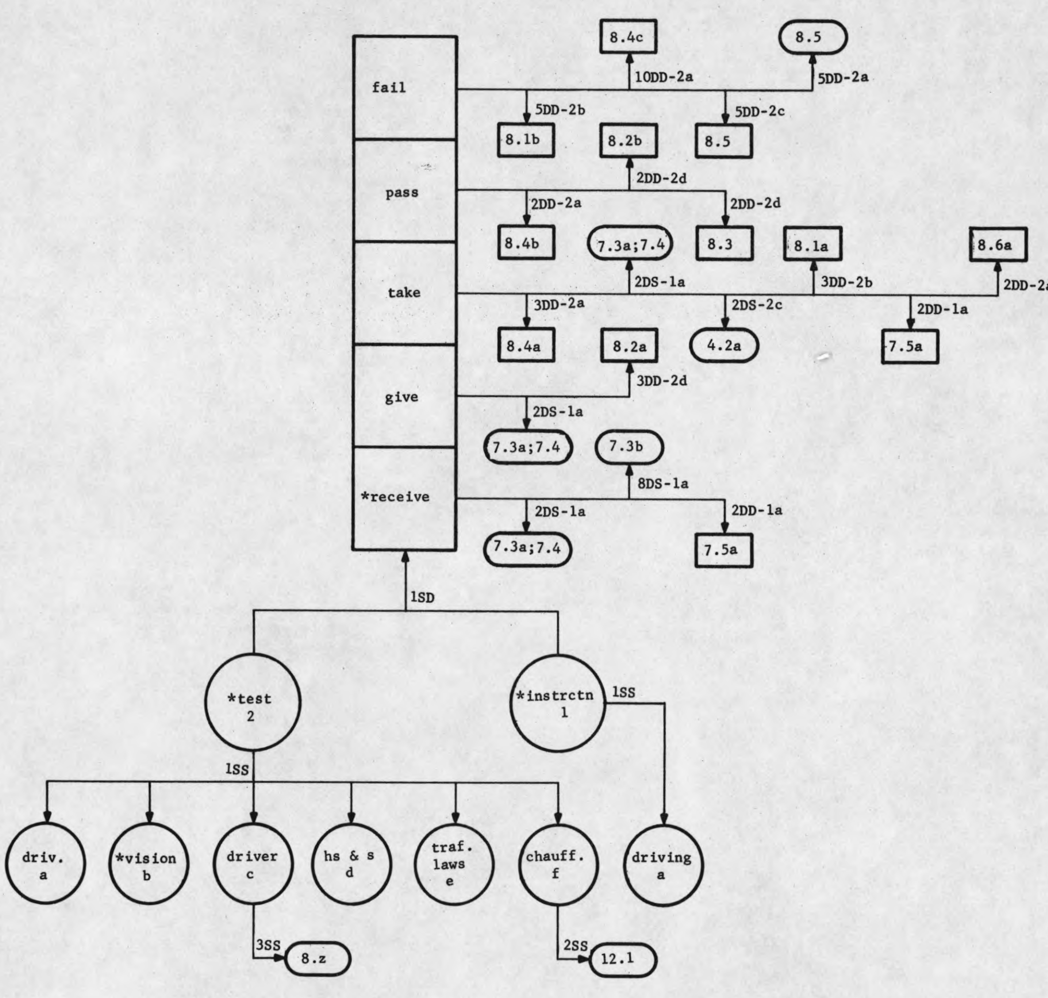
Naturally, this model was designed primarily for use in the cognitive memory of the R2 question-answering system. In light of this fact, it becomes necessary to consider the question-answering properties of this model in detail and to give examples of the question analysis and search procedure that facilitates the most effective use of this model in a question-answering system.

Basically, the question answering procedure can be divided up into the following three phases: the syntactic analysis (or parsing of the question), the semantic analysis or interpretation, and the retrieval or search procedure. The first two phases of this procedure deal with the formulation of a set of information from the given question. The third phase then uses this set of information as a guide and a reference in searching the model for the correct answer. For example, the question "Where do you obtain a driver's license?" contains the following set of information: 2DS-1, where 2DS is the RDC and 1 is the address of the Major Static Independent Node containing the word "driver's license". Obtaining the address of the "driver's license" node is simply a matter of searching all the Major Static Nodes for the word "driver's license" after the appropriate parsing algorithm has been applied. However, the problem of deducing the appropriate RDC from the parsed question is a considerable one. This problem of carrying out semantic interpretation procedures rather than merely matching a structure in the data base is the same one that Woods[4] was confronted with. In solving the problem, Woods developed a "semantic interpreter" that bridged the gap between the parsed question and his "semantic primitives" and their respective subroutines. These semantic primitives are analogous to the RDC's discussed in this model and, consequently, with some adaptation and extension, this "semantic interpreter" can be implemented within the present framework. Once the interpretation is complete, and the required set of information is deduced from the question, the search procedure can be executed. Referring back to the sample question "Where do you obtain a driver's license?", the "semantic interpreter" will yield the RDC 2DS and the parser will identify the Major Independent Static Node to be located, namely the one containing the word "driver's license". The most efficient way to perform this search would be to use an associative technique and to scan all the nodes simultaneously. In any case, once this node (or block as it is referred to in linked list computer storage terminology) is located, its address will be stored and the pointers within the block will be referenced. One pointer will contain the addresses of all the various <u>types</u> of "driver's licenses" (see Fig. 2) and the other pointer will contain the address of all the dynamic nodes (or blocks) in that particular data cell (i.e., data cell #2). If a particular type of "driver's license" is called for, such as a "duplicate license" then the Major <u>Dependent</u> Static Nodes are scanned for the word "duplicate" and its address is recorded. In the example given this does not occur, so now the list of dynamic nodes is scanned for the word "obtain". This node (or block) has fields containing the information shown in the channel emitting from the block "obtain" in Fig. 2. This information, such as 2DS-1, 6DS-1, 2DS-2, etc., is also supplemented with pointers.

Now it is necessary to find the best match between the set of information obtained from the question and the information stored in the afore mentioned block. The best match can be defined in the following way: Let A be the set of information obtained from the question and B be the set of stored information, then the largest B such that $B \subseteq A$ defines the best possible match. Once this match has been made, the specific information relating to it (i.e., 4.2a, 5.12, 7.5b, etc.) will be pointed to and selected. For example, the question given previously was said to yield the following set of information: 2DS-1. Since the "obtain" block contains an identical set of information, the best match in this case is obvious and the information accessed would be 4.2a. However, supposing the question had been, "How do you park a car on the downward slope of a hill?". After the appropriate parsing has been carried out and the addresses of the Major Independent Static Node and the appropriate Modifiers stored, the question yields the following set of information as can be seen from Fig. 4 and Fig. 5: 4DD-1a-7b4c. Now searching the block "park" for the best match using the criterion specified earlier, the set of information 4DD(8DD)-4c is chosen. The respective pointer is to 67.1b which reads, "If you park on a hill you must turn the front wheels to the curb. Then you must set the emergency or parking brake." If we consider the same question phrased a little differently the reason for the set inclusive type addressing mentioned earlier becomes obvious. Supposing the question had been, "How do you park on the downward slope of a hill?". This is, in fact, a more likely phrasing of the question. The set of information obtained from this question would be 4DD-4c7b. The best possible match is still 4DD-4c, but if the address of the node "vehicle" had been included in the stored set of information (i.e., 4DD-1-4c), then no match would be possible under the specified criterion since the stored information would contain an address not appearing in the set obtained from the question (i.e., 4DD-4c7b). Therefore, the set of information stored in the memory must correspond to the <u>shortest</u> possible set of information an "unambiguous" question can have.

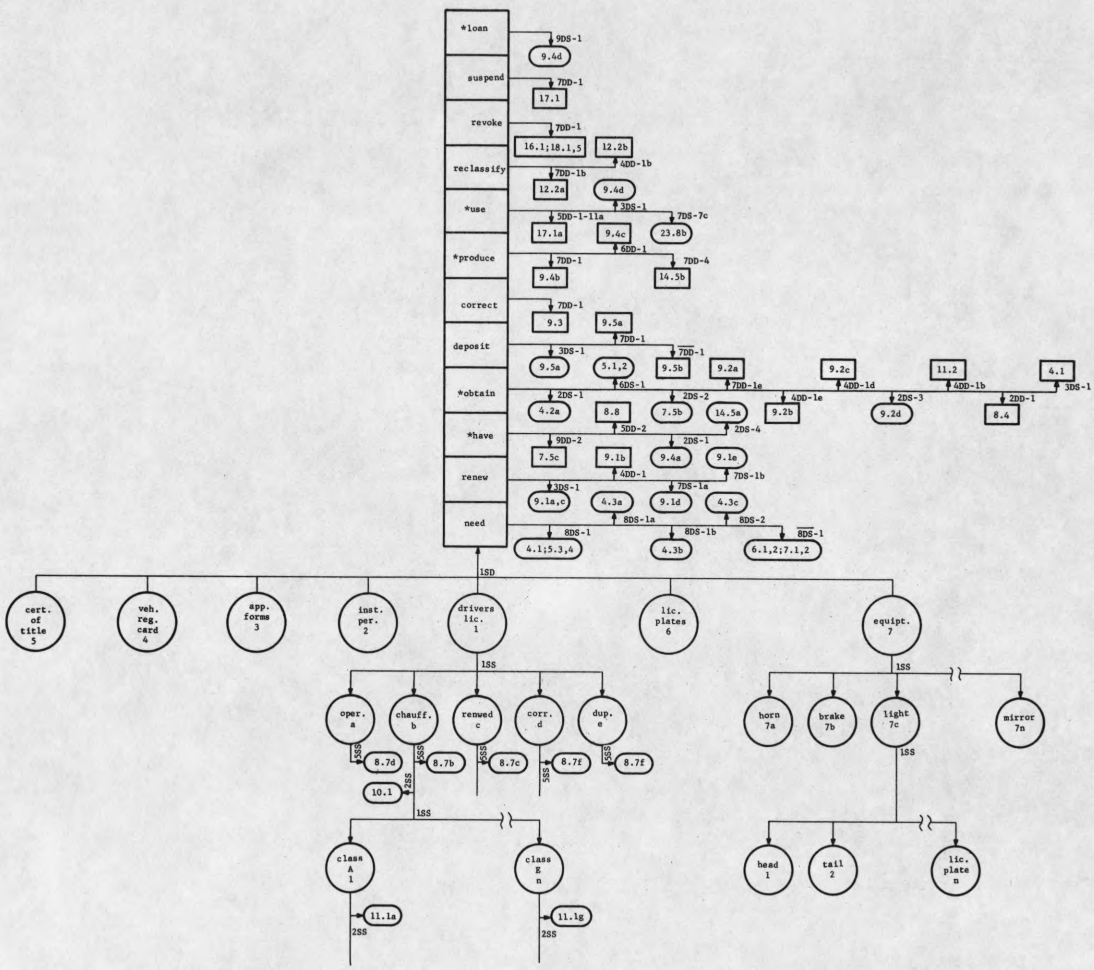
As one final example, consider the question, "What does a triangular sign mean?". Using a suitable parsing algorithm in conjunction with Woods interpreter will yield the RDC 2ss (i.e., specifies the definition or the meaning of an object) and the Major Independent Static Node "sign". In this case, however, the adjective "triangular" is also noted and the Major Dependent Static Nodes relating to the node "sign" are searched since "triangular" is a type of sign. Now since all the parameters have been specified and there is no Dynamic Node to be referenced, once the node containing the word "triangular" is located, its fields are scanned for the information 2SS and it's respective pointer. As a consequence, the passage 28.2c is selected and it reads "Yield the Right-of-Way".

Unfortunately, at this time it is not possible to give all the details pertinent to the actual implementation of this system. However, the somewhat heuristic methods outlined here define a reasonable set of guidelines for the design of the actual algorithms needed for implementation.



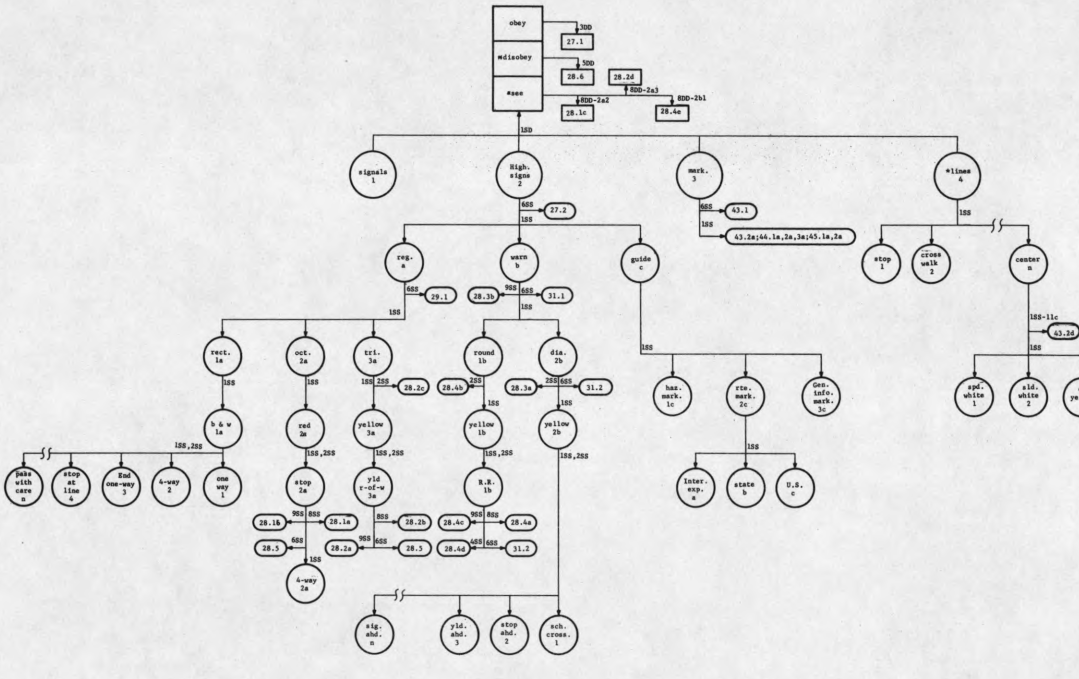
*synonyms (see Appendix)

Figure 1. Data Cell #1



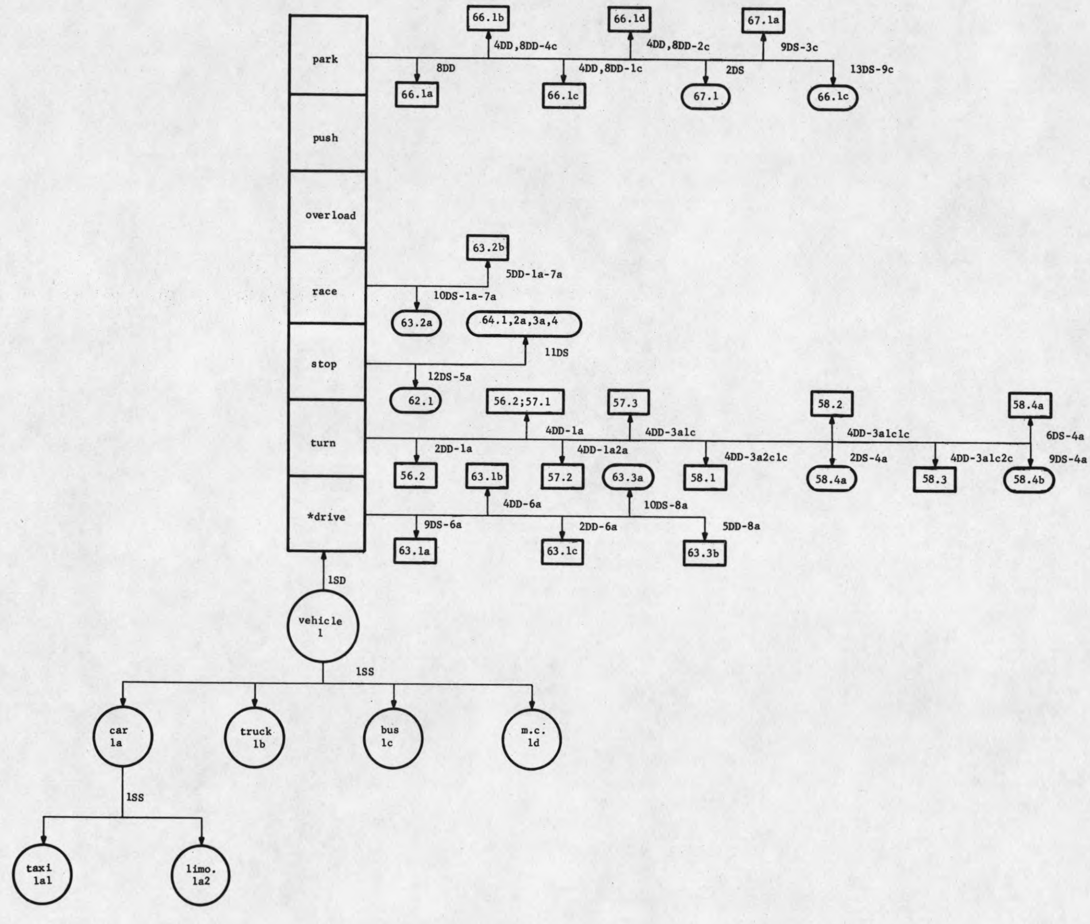
*synonyms (see Appendix)

Figure 2. Data Cell #2



*synonyms (see Appendix)

Figure 3. Data Cell #3



*synonyms (see Appendix)

Figure 4. Data Cell #4

ADJECTIVES & ADVERBS		CONDITIONS	LOCATIONS	
*safe 1a	fradulent 11a	rain 1b	two-way street 1c	4-lane highway 11c
right 2a	double 12a	snow 2b	one-way street 2c	expressway 12c
left 3a	4-way 13a	fog 3b	sidewalk 3c	ramp 130
U 4a		accident 4b	hill 4c	
*quick 5a		another driver 5b	crosswalk 5c	
*drunk 6a		up ahead 6b	intersection 6c	
drag 7a		dnward slope 7b	safety zone 7c	
*reckless 8a			R.R. crossing 8c	
*prohibit 9a			curb 9c	
*legal 10a			fire hydrant 10c	

*synonyms (see Appendix)

Figure 5. Modifiers

APPENDIX

Synonym Dictionary

allowed: legal

approach: see

arrive at: see

be at: see

be equipped with: have

carry: have

come to: see

display: produce

eye: vision

examination: test

fast: quick

get: receive, obtain

ignore: disobey

illegal: prohibit

intoxicated: drunk

lessons: instruction

let another person use

lose: revoke

negligent: reckless

not allowed: prohibit

not permitted: prohibit

not prohibited: permitted

APPENDIX (continued)

operate a motor vehicle: drive

permit another person to use: loan

permitted: legal

possess: have

proper: safe

run through: disobey

show: produce

square: rectangular

stripes: lines

turn on: use

unlawful: fraudulent

LIST OF REFERENCES

1. C. Green and B. Raphael, "Research on Intelligent Question-Answering System," Stanford Research Institute Project 6001, May 1967.

2. B. Raphael, "SIR: A Computer Program for Semantic Information Retrieval," MAC-TR2, Project MAC, MIT, June, 1964.

3. J. Jensen, "Phrase Dictionary Construction Methods for the R2 Information Retrieval System," to appear, CSL, Univ. of Ill., Urbana, Illinois.

4. W. A. Woods, "Procedural Semantics for a Question-Answering Machine," 1968 Fall Joint Computer Conference Convention Record, November 1968, pp. 457-471.

Distribution List as of November 1, 1968

1 Dr A.A. Dougal
Asst Director (Research)
Ofc of Defense Res & Eng
Department of Defense
Washington, D.C. 20301

1 Office of Deputy Director
(Research and Technology)
ODD R&E-OSD
The Pentagon, Room 3-E-144
Washington, D.C. 20301

1 Director Advanced Research Projects Agency
Department of Defense
Washington, D.C. 20301

1 Director for Information Sciences
Advanced Research Projects Agency
Department of Defense
Washington, D.C. 20301

1 Director for Materials Sciences
Advanced Research Projects Agency
Department of Defense
Washington, D.C. 20301

1 Headquarters
Defense Communications Agency (333)
The Pentagon
Washington, D.C. 20305

20 Defense Documentation Center
Attn: TISIA
Cameron Station, Bldg 5
Alexandria, Virginia 22314

1 Director
National Security Agency
Attn: Librarian C-332
Fort George G. Meade, Maryland 20755

1 Weapons Systems Evaluation Group
Attn: Col Daniel W. McElwee
Department of Defense
Washington, D.C. 20305

1 National Security Agency
Attn: R4-James Tippett
Office of Research
Fort George G. Meade, Maryland 20755

1 Central Intelligence Agency
Attn: OCR/DD Publications
Washington, D.C. 20505

1 Colonel Kee
AFRSTE
Hqs, USAF
Room ID-429, The Pentagon
Washington, D.C. 20330

1 Aerospace Medical Division
AMD (AMRXI)
Brooks Air Force Base, Texas 78235

1 AUL3T-9663
Maxwell AFB, Alabama 36112

1 AFFTC (FTBPP-2)
Technical Library
Edwards AFB, Calif. 93523

1 Hq SAMSO (SMITA/Lt Nelson)
AF Unit Post Office
Los Angeles, California 90045

1 Lt Col Charles M. Waespy
Hq USAF (AFRDSD)
Pentagon
Washington, D.C. 20330

1 SSD (SSTRT/Lt Starbuck)
AFUPO
Los Angeles, California 90045

1 Det #6, OAR (LOOAR)
Air Force Post Office
Los Angeles, California 90045

1 ARL (ARIY)
Wright-Patterson AFB, Ohio 45433

1 Dr H.V. Noble
Air Force Avionics Laboratory
Wright-Patterson AFB, Ohio 45433

1 Mr Peter Murray
Air Force Avionics Laboratory
Wright-Patterson AFB, Ohio 45433

1 AFAL (AVTE/R.D. Larson)
Wright-Patterson AFB, Ohio 45433

2 Commanding General
Attn: STEWS-WS-VT
White Sands Missile Range
New Mexico, 88002

1 RADC (EMLAL01)
Griffiss AFB, New York 13442
Attn: Documents Library

1 Mr H.E. Webb (EMIA)
Rome Air Development Center
Griffiss AFB, New York 13442

1 Academy Library (DFSLB)
U.S. Air Force Academy
Colorado Springs, Colorado 80912

1 Mr Morton M. Pavane, Chief
AFSC Scientific and Liaison Office
26 Federal Plaza
New York, N.Y. 10007

1 Lt Col Bernard S. Morgan
Frank J. Seiler Research Laboratory
U.S. Air Force Academy
Colorado Springs Colorado 80912

1 Technical Library, AFETR
(ETV, MU-135)
Patrick AFB, Florida 32925

1 AFETR (ETLLG-1)
STINFO Office (For Library)
Patrick AFB, Florida 32925

1 Dr L. M. Hollingsworth
AFCRL (CRN)
L.G. Hanscom Field
Bedford, Massachusetts 01731

1 AFCRL (CRMZLR)
AFCRL Research Library, Stop 29
L.G. Hanscom Field
Bedford, Mass 01731

1 Colonel Robert E. Fontana
Dept of Electrical Engineering
Air Force Institute of Technology
Wright-Patterson AFB, Ohio 45433

1 Colonel A.D. Blue
RTD (RTTL)
Bolling Air Force Base, D.C. 20332

1 Dr I.R. Mirman
AFSC (SCT)
Andrews AFB, Maryland 20331

1 AFSC (SCTR)
Andrews AFB, Maryland 20331

1 Lt Col J.L. Reeves
AFSC (SCBB)
Andrews AFB, Maryland 20331

2 ESD (ESTI)
L.G. Hanscom Field
Bedford, Mass 01731

1 AEDC (ARO, INC)
Attn: Library/Documents
Arnold AFS, Tenn 37389

2 European Office of Aerospace Research
Shell Building
47 Rue Cantersteen
Brussels, Belgium

5 Lt Col Robert B. Lalisch
Chief, Electronics Division
Directorate of Engineering Sciences
Air Force Office of Scientific Research
Arlington, Virginia 22209

1 APGC (PGBS-12)
Elgin AFB, Florida 32542

1 U.S. Army Research Office
Attn: Physical Sciences Division
3045 Columbia Pike
Arlington, Virginia 22204

1 Research Plans Office
U.S. Army Research Office
3045 Columbia Pike
Arlington, Virginia 22204

1 Commanding General
U.S. Army Materiel Command
Attn: AMCRD-TP
Washington, D.C. 20315

1 Commanding General
U.S. Army Strategic Communication Command
Fort Huachuca, Arizona 85613

1 Commanding Officer
Army Materials & Mech. Res. Center
Watertown Arsenal
Watertown, Mass. 02172

1 Commanding Officer
U.S. Army Ballistics Research Laboratory
Attn: AMXRD-BAT
Aberdeen Proving Ground
Aberdeen, Maryland 21005

1 Commandant
U.S. Army Air Defense School
Attn: Missile Sciences Division
C & S Dept
P.O. Box 9390
Fort Bliss, Texas 79916

1 Commanding General
U.S. Army Missile Command
Attn: Technical Library
Redstone Arsenal, Alabama 35809

1 U.S. Army Munitions Command
Attn: Technical Information Command
Picatinney Arsenal
Dover, New Jersey 07801

1 Commanding Officer
Harry Diamond Laboratories
Attn: Dr Berthold Altman (AMXDO-TI)
Connecticut Ave & Van Ness St. N.W.
Washington, D.C. 20438

1 Commanding Officer
U.S. Army Security Agency
Arlington Hall
Arlington, Virginia 22212

1 Commanding Officer
U.S. Army Limited War Laboratory
Attn: Technical Director
Aberdeen Proving Ground
Aberdeen, Maryland 21005

1 Commanding Officer
Human Engineering Laboratories
Aberdeen Proving Grounds
Aberdeen, Maryland 21005

1 Commandant
U.S. Army Command & General Staff
College
Attn: Secretary
Fort Leavenworth, Kansas 66270

1 Commanding Officer
U.S. Army Research Office (Durham)
Attn: CRD-AA-IP (Richard O. Ulsh)
Box CM, Duke Station
Durham, North Carolina 27706

1 Librarian
U.S. Army Military Academy
West Point, New York 10996

1 The Walter Reed Institute of Research
Walter Reed Medical Center
Washington, D.C. 20012

1 Commanding Officer
U.S. Army Electronics R & D Activity
White Sands Missile Range
New Mexico 88002

1 Dr H. Robl
Deputy Chief Scientist
U.S. Army Research Office (Durham)
Box CM, Duke Station
Durham, North Carolina 27706

1 U.S. Army Mobility Equipment
Research & Development Center
Attn: Technical Document Center
Bldg 315
Fort Beloir, Virginia 22060

1 Mr Norman J. Field (AMSEL-RD-S)
Chief, Office of Science & Technology
U.S. Army Electronics Command
Fort Monmouth, New Jersey 07703

1 Mr Robert O. Parker
Executive Secretary,
JSTAC (AMSEL-XL-D)
Fort Monmouth, New Jersey 07703

1 Commanding General
U.S. Army Electronics Command
Fort Monmouth, New Jersey 07703
Attn: AMSEL-SC
RD-D
RD-G
RD-GF
RD-MAT
XL-D
XL-E (Dr K. Schwidta)
XL-C
XL-S
HL-D
HL-CTR
HL-CT-P (Dr W. McAfee)
HL-CT-L
HL-CT-O
HL-CT-I
HL-CT-A
NL-D
NL-A
NL-P-2 (D. Haratz)
NL-R
NL-S
KL-D
KL-E
KL-S
KL-T
VL-F (R.J. Niemela)
WL-D

1 Cy to each symbol listed.

1 Director Night Vision Laboratory
U.S. Army Electronics Command
Attn: HL-NV-II (Dr A.D. Schnitzler
Fort Belvoir, Virginia 22060

1 Components Research Laboratory
(P.E. Landis) Bldg 92
Harry Diamond Laboratories
Connecticut Ave & Van Ness St N.W.
Washington, D.C. 20438

1 Mr Edward Vaughan
Research & Engineering Directorate
U.S. Army Weapons Command
Rock Island, Illinois 61201

1 Commanding General
U.S. Army Missile Command
AMSMI-REX (W. Todd)
Redstone Arsenal, Ala 35809

3 Chief of Naval Research
Department of the Navy
Washington, D.C. 20360
Attn: Code 427

2 Naval Electronics Systems Command
ELEX 03
Falls Church, Virginia 22046

1 Naval Ship Systems Command
SHIP 031
Washington, D.C. 20360

1 Naval Ships Systems Command
SHIP 035
Washington, D.C. 20360

2 Naval Ordnance Systems Command
ORD 32
Washington, D.C. 20360

2 Naval Air Systems Command
AIR 03
Washington, D.C. 20360

2 Commanding Officer
Office of Naval Research Branch Office
Box 39, Navy No.100 F.P.O.
New York, New York 09510

1 Commanding Officer
Office of Naval Research Branch Office
219 South Dearborn Stree
Chicago, Illinois 60604

1 Commanding Officer
Office of Naval Reserve Branch Office
207 West 24th Street
New York, New York 10011

1 Commanding Officer
Office of Naval Research Branch Office
1030 East Green Street
Pasadena, California 91101

1 Commanding Officer
Office of Naval Research Branch Office
495 Summer Street
Boston, Massachusetts 02210

8 Director, Naval Research Laboratory
Technical Information Officer
Washington, D.C. 20360
Attn: Code 2000

1 Commander
Naval Air Development & Material Center
Johnsville, Pennsylvania 18974

2 Librarian
U.S. Naval Electronics Laboratory
San Diego, California 95152

1 Commanding Officer & Director
U.S. Naval Underwater Sound Laboratory
Fort Trumbull
New London, Connecticut 06840

1 Librarian
U.S. Naval Post Graduate School
Monterey, California 93940

1 Commander
U.S. Naval Air Missile Test Center
Point Magu, California 93041

1 Director
U.S. Naval Observatory
Washington, D.C. 20390

2 Chief of Naval Operations
OP-07
Washington, D.C. 20350

1 Director, U.S. Naval Security Group
Attn: G43
3801 Nebraska Avenue
Washington, D.C. 20390

2 Commanding Officer
Naval Ordnance Laboratory
White Oak, Maryland 21502

1 Commanding Officer
Naval Ordnance Laboratory
Corona, California 91720

1 Commanding Officer
Naval Ordnance Test Station
China Lake, California 93555

1 Commanding Officer
Naval Training Device Center
Orlando, Florida 32811

1 Commanding Officer
Naval Avionics Facility
Indianapolis, Indiana 46241

1 U.S. Naval Weapons Laboratory
Dahlgren, Virginia 22448

1 Weapons Systems Test Division
Naval Air Test Center
Patuxtent River, Maryland 20670
Attn: Library

1 Head, Technical Division
U.S. Naval Counter Intelligence
Support Center
Fairmont Building
4420 North Fairfax Drive
Arlington, Virginia 22203

1 Mr Charles Yost
Special Asst to the Director of Res.
National Aeronautics & Space Admin.
Washington, D.C. 20546

1 Dr H. Harrison, Code RRE
Chief, Electrophysics Branch
National Aeronautics & Space Admin.
Attn: Library C3/TDL
Green Belt, Maryland 20771

1 NASA Lewis Research Center
Attn: Library
21000 Brookpark Road
Cleveland, Ohio 22135

1 National Science Foundation
Attn: Program Director
Engineering System Program ENG
1800 G. Street, N.W.
Washington, D.C. 20550

1 U.S. Atomic Energy Commission
Division of Technical Information Ext.
P.O. Box 62
Oak Ridge, Tenn. 37831

1 Los Alamos Scientific Laboratory
Attn: Reports Library
P.O. Box 1663
Los Alamos, New Mexico 87544

2 NASA Scientific & Technical Inform. Fac.
Attn: Acquisitions Branch (S/AK/DL)
P.O. Box 33
College Park, Maryland 20740

1 Director
Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Mass 02139

1 Polytechnic Institute of Brooklyn
55 Johnson Street
Brooklyn, New York 11201
Attn: Mr Jerome Fox
Research Coordinator

1 Director
Columbia Radiation Laboratory
Columbia University
538 West 120th Street
New York, New York 10027

1 Director
Coordinated Science Laboratory
University of Illinois
Urbana, Illinois 61801

1 Director
Stanford Electronics Laboratories
Stanford University
Stanford, California 94305

1 Director
Electronics Research Laboratory
University of California
Berkeley, California 94720

1 Director
Electronic Sciences Laboratory
University of Southern California
Los Angeles, California 90007

1 Electronics Research Center
University of Texas at Austin
Engr-Science Bldg 110
Austin, Texas 78712

1 Division of Engineering &
Applied Physics
210 Pierce Hall
Harvard University
Cambridge, Massachusetts 02138

1 Aerospace Corporation
P.O. Box 95085
Los Angeles, California 90045
Attn: Library Acquisition Group

1 Professor Nicholas George
California Inst. of Technology
Pasadena, California 91109

1 Aeronaurics Library
Graduate Aeronautical Laboratories
California Institute of Technology
1201 E. California Blvd
Pasadena, California 91109

1 Director, USAF Project Rand
Via: Air Force Liaison Office
The Rand Corporation
1700 Main Street
Santa Monica, California 90406

1 Hunt Library
Carnegie Institute of Technology
Schenley Park, Pittsburgh, Pa. 15213

1 Syracuse University
Dept of Electrical Engineering
Syracuse, New York 13210

1 Yale University
Engineering Dept
New Haven, Connecticut 06520

1 Airborne Instruments Laboratory
Deerpark, New York 11729

1 Bendix Pacific Division
11600 Sherman Way
North Hollywood, California 91605

1 General Electric Co
Research Laboratories
Schenectady, New York 12301

1 Lockheed Aircraft Corp
P.O. Box 504
Sunnyvale, California 94088

1 Raytheon Co
Bedford, Mass 01730
Attn: Librarian

1 Dr G. J. Murphy
The Technological Institute
Northwestern University
Evanston, Illinois 60201

1 Dr John C, Hancock, Director
Electronics Systems Research Laboratory
Purdue University
Lafayette, Indiana 47907

1 Director
Microwave Laboratory
Stanford University
Stanford, California 94305

1 Emil Schafer, Head
Electronics Properties Infor. Center
Hughes Aircraft Co
Culver, California 90230

1 The John Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Springs, Maryland 20910
Attn: Boris W. Kuvshinoff
Document Librarian

1 Dr Leo Young
Stanford Research Institute
Menlo Park, California 94025

1 Mr Henry Bachmann
Assistant Chief Engineer
Wheeler Laboratories
122 Cutterhill Road
Great Neck, New York 11021

1 School of Engineering Sciences
Arizona State University
Tempe, Arizona 85281

1 Engineering & Math Sciences Library
University of California at Los Angeles
405 Hilgred Avenue
Los Angeles, California 90024

1 California Institute of Technology
Pasadena, California 91109
Attn: Documents Library

1 University of California
Santa Barbara, California 93106
Attn: Library

1 Carnegie Institute of Technology
Electrical Engineering Dept
Pittsburgh, Pa 15213

1 University of Mighigan
Electrical Engineering Dept
Ann Arbor, Michigan 48104

1 New York University
College of Engineering
New York, N.Y. 10019

1 Dept of Electrical Engineering
Texas Technological College
Lubbock, Texas 79409

1 IBM Technical Info. Retrieval Center
International Business Machines Corp.
Armonk, New York 10504

1 Commander
Test Command (TCDT-E)
Defense Atomic Support Agency
Sandia Base
Albuquerque, New Mexico 87115

1 Commanding General
U.S. Army Weapons Command
Rock Island, Ill 61201
Attn: ANSWE-RDR (Gerald Reinsmith)

1 Col E.P. Gaines, ACDA/FO
1901 Pennsylvania Ave, N.W.
Washington, D.C. 20451

1 Mr Billy Locke
Plans Directorate
USAF Security Service
Kelly Air Force Base, Texas 78241

1 W.A. Eberspacher
Technical Consultant
Systems Integration
Code 5340A, Box 15
Naval Missile Center
Point Magu, California 93041

1 Director of Faculty Research
Department of the Air Force
USAF Academy
Colorado 80840

1 Lt Col Richard Bennett
AFRDD
The Pentagon
Washington, D.C. 20301

1 Weapons Systems Evaluation Group
Attn: Col John B. McKinney
410 Army-Navy Drive
Arlington, Virginia 22202

1 Mr M. Zane Thornton
National Library of Medicine
8600 Rockville Pike
Bethesda, Maryland 22014

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
University of Illinois Coordinated Science Laboratory Urbana, Illinois 61801	Unclassified 2b. GROUP

3. REPORT TITLE

CONTEXT MODELING IN A COGNITIVE MEMORY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

LOMBARDI, Daniel Joseph

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1969	27	4

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
OE C-1-7-071213-4557; Also in part DAAB 07-67-C-0199. b. PROJECT NO.	R-408
c. d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this report is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Joint Services Electronics Program thru U.S. Army Electronics Command Fort Monmouth, New Jersey 07703

13. ABSTRACT

This report is concerned with the derivation and description of a model used for structuring the "Rules of the Road" as a data base for a general question answering system. Related work and question-answering processes are also discussed.

DD FORM 1 NOV 65 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Semantic Model						
Data Cells						
Fact Storage						
Information Structures						
Information Retrieval						

Security Classification